The very important outbound uplink (ground station to satellite) margin with the spectrum spreading will help protect the outbound STARNET uplink against other services.

B. SPACE SEGMENT DESCRIPTION

The LEO satellites are designed to be small, lightweight and inexpensive. In the stowed position, the spacecraft measure dimensions are a 0.81^2 m, 1.2 m in height, weighing 112 kg and consuming, 115 watts.

In orbit, the solar panels and a gravity gradient boom will be deployed. The satellite dimensions will then be 3 x 8 m.

1. Basic Structure

The STARNET structure is illustrated in Figure VII.B, which shows the spacecraft in orbital configuration. Figure VII.B.1, shows the general arrangement of the spacecraft subsystems and the structural parts description.

The connection between the flange and adapter will be accomplished with a clamp strap. The release of the spacecraft from the adapter will be performed by the firing of squib-operated separation clamp bolt cutters. Upon release, separation springs impart the separation velocity.

The attach flange will be integrated with the “central conical tube” to support the “electronics deck”. Truss assemblies extend from the attach flange of the central type to the perimeter of the electronics deck. They give diagonal support to the overhanging electronics deck and provide longitudinal stiffeners for the conical tube.

The electronics deck will be aluminium honeycomb panel mounted on top of the central tube. The deck will be a 32 inch square (.8 m square). The electronics packages associated with all of the spacecraft subsystems and communication equipment are mounted on

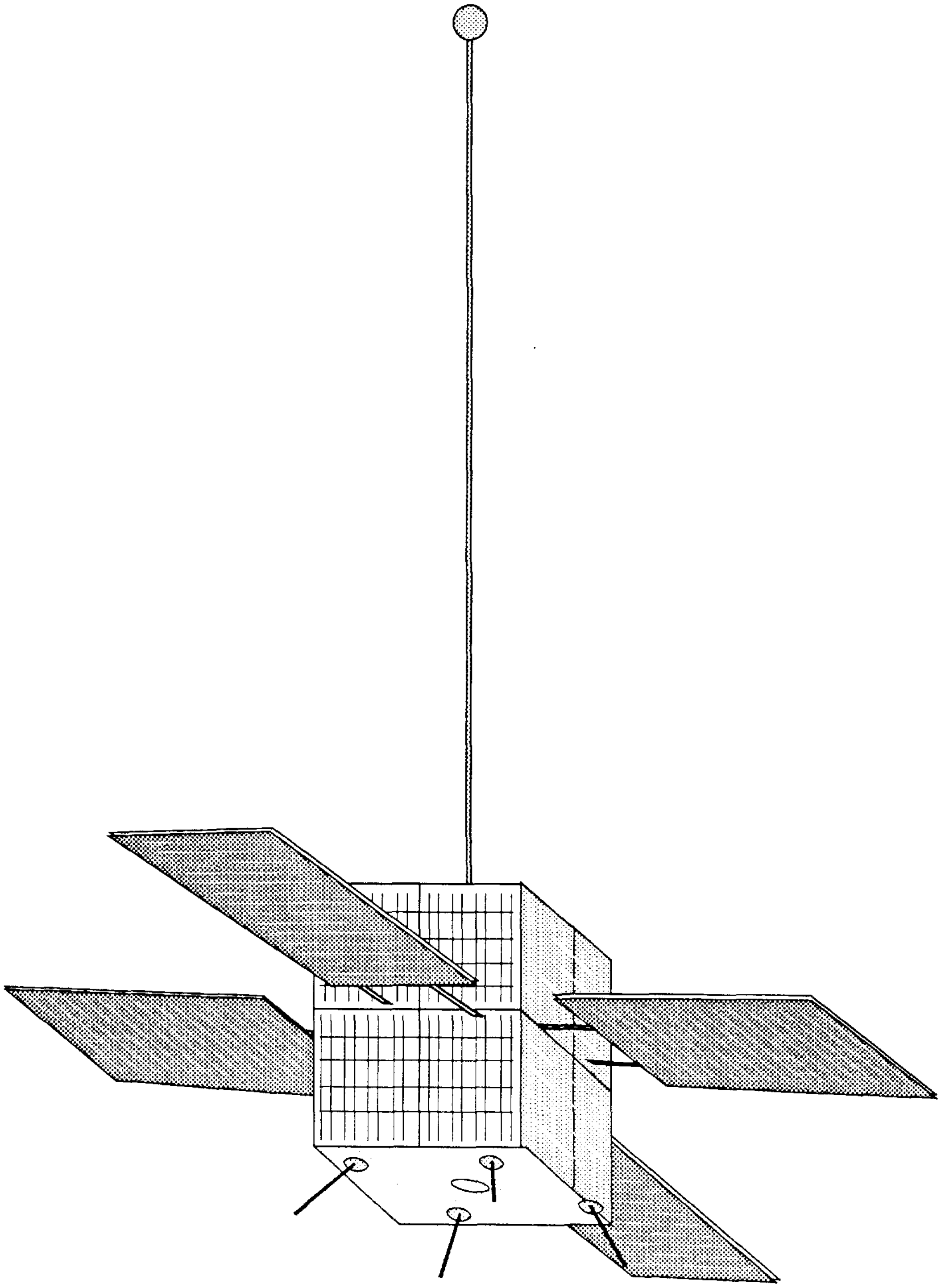


Figure VII.B

one side of this deck, with the gravity-gradient boom assemblies and the thermal louver assemblies on the other.

1.1 Solar panels

The solar array electrical requirements are discussed in Section 2.1. To meet these requirements, a deployable array will be designed. There will be four identical panels with cells on both sides. The solar cells are mounted on "substrates". To streamline the procurement process, the same cell layout will be used on all panels (and sides).

The deployment of the panels is driven by the helical springs and controlled by dampers which only act during the over-travel past the desired deployed position.

The deployed position is adjustable in the mechanism and does not depend on the spring which is still loaded at equilibrium. A positive stop is provided, beyond the expected range of motion, to prevent any contact of the panels with the spacecraft, or each other.

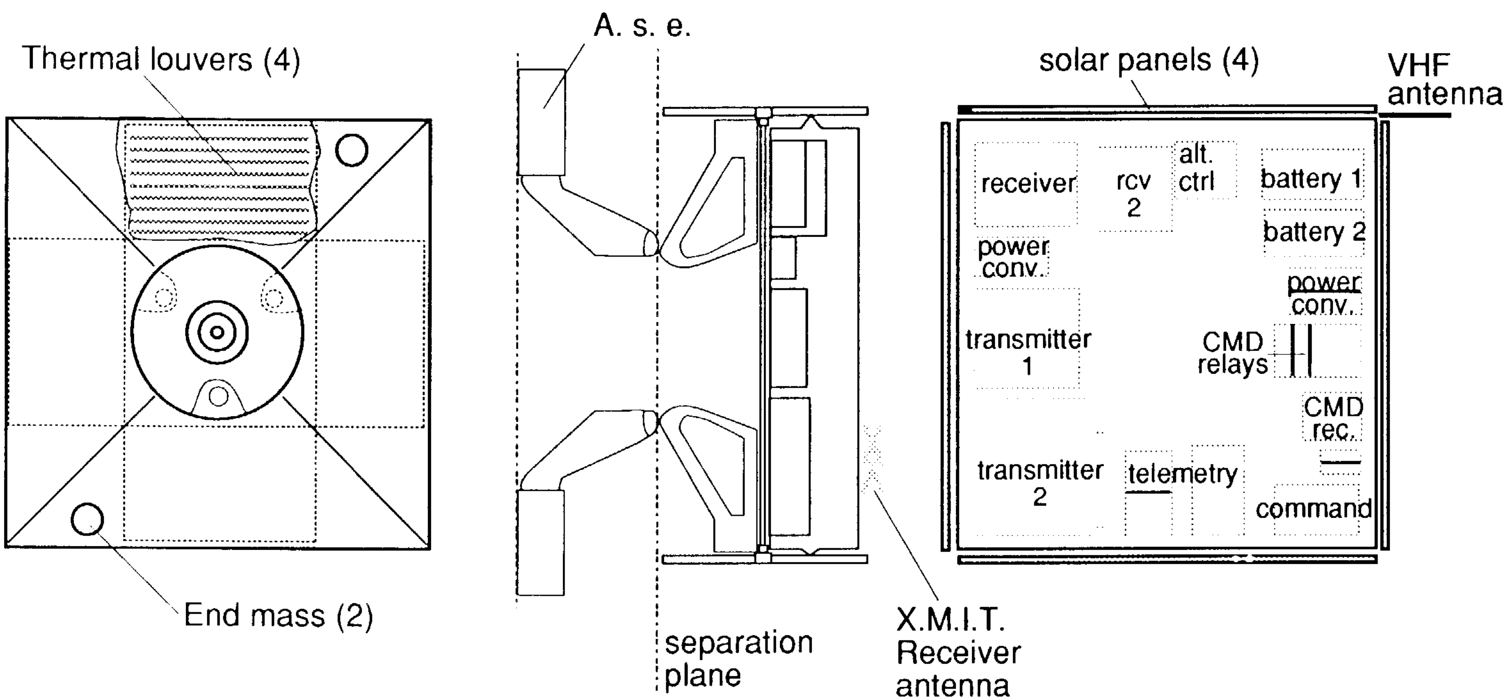
1.2 System Block Diagram and Power Budget

The satellite is composed of the following subsystems :

1. Power
2. Thermal
3. Command
4. Telemetry
5. Attitude
6. Antennas
7. Communication transmit and receive

Power evaluation is based on the following assumptions :

1. Converter efficiency is 85%.
2. Command converter efficiency is 75%.
3. The communication equipment has one power mode.



SATELLITE GENERAL ARRANGEMENT

Figure VII.B.1

4. The attitude system is turned off after the satellite is captured in the proper orbit.
5. Thermal control is cycled as required.

Spacecraft weight and power allocation :

Four (4) solar array panels will extend from four (4) sides on the top of the spacecraft. Each of the panels will be approximately 0.7 square meter.

The solar cells combined with two 10 AH Ni-cad batteries will supply sufficient energy to accommodate an average requirement of 115 watts (50% efficiency).

• Spacecraft structure	33 kg	
• Batteries	15 kg	
• Solar cells	15 kg	
• Power control unit	2 kg	7 Watts
• Thermal control	10 kg	14 Watts
• Attitude control	8 kg	10 Watts
• Gravity gradient boom	5 kg	
• VHF antennas	6 kg	
• RF payload and switching	10 kg	10 Watts
• Power stages (37 Watts, 50% efficiency)	8 kg	74 Watts
Total weight/power	112 kg	115 Watts

2. Power Subsystem

The power subsystem will be required to support an estimated average electrical load of approximately 125 watts during its five (5) year lifetime in orbit. The power subsystem to support this load will consist of a solar cell array for power generation, nickel cadmium batteries, battery charge regulators and DC/DC converters for conditioning power to selected loads.

The energy generating and storage systems will provide power to the main power bus at a nominal operating voltage of 28 volts.

2.1 Solar Array

The solar array will consist of four panels which, when deployed, will form an omni-directional turnstile array. Each of the four panels will mount high efficiency, shallow diffused, N/P solar cells on both sides. Each panel will have a platform area of approximately 1.4 square meter. The array is designed to accommodate the degradation in electrical performance anticipated after five (5) years in a high inclination orbit at an altitude in the range of from 1000 to 1300 km.

2.2 Batteries

The power system will incorporate redundant nickel cadmium batteries to supply peak energy demands in excess of instantaneous solar array generating capability and to power the spacecraft during periods of solar eclipse lasting up to approximately 45 minutes. Each battery will consist of 22 series 10 ampere-hour cells, operating at a nominal 28 volts. During normal spacecraft operation, both batteries will be available to provide power to the spacecraft main power bus. A total energy of approximately 672 watt-hours is therefore available when the batteries are fully charged.

Each battery may be individually removed from service by ground command for a periodic reconditioning cycle if desired. This reconditioning process, which removes memory effects, can be performed during periods of 100% sunlight exposure when energy storage demands are minimal (see Figure VII.B.2.2).

2.3 Battery Charge Control

Battery charge control is accomplished by a redundant, microprocessor-based, non-dissipative charge controller. The battery charge controller senses battery temperature, charge current, bus

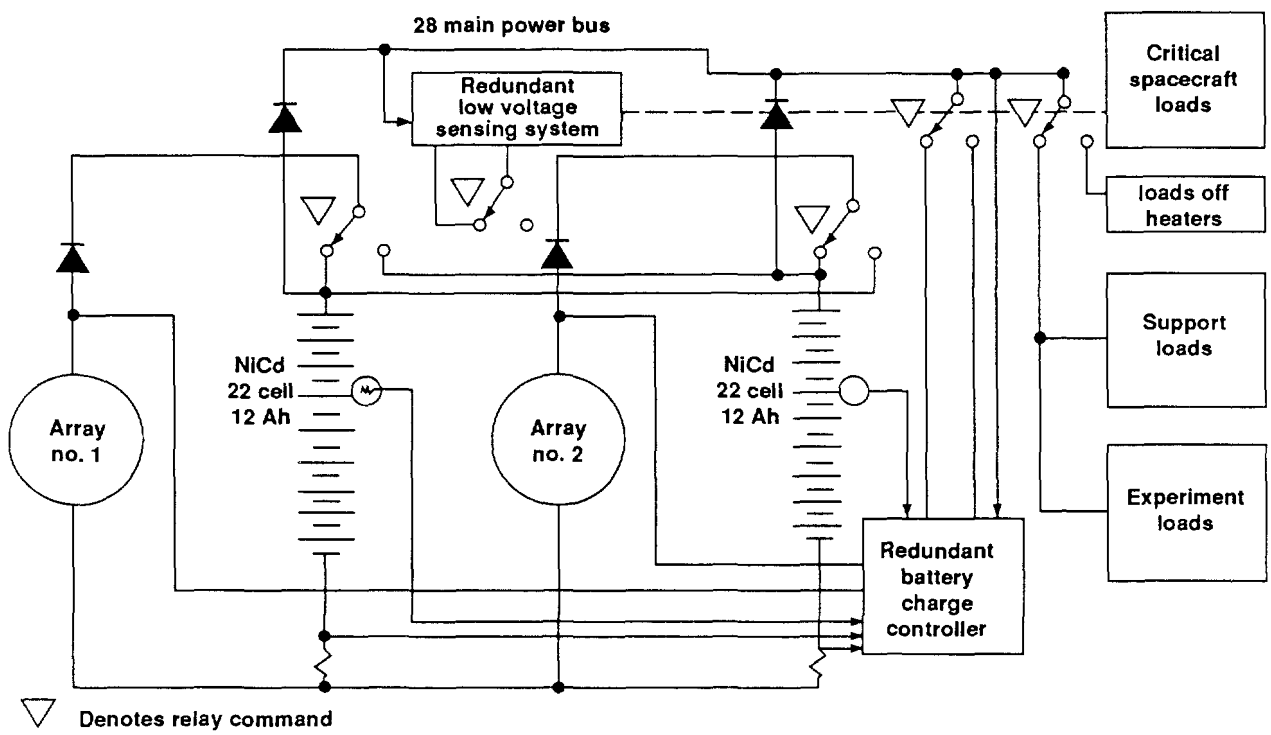


Figure VII.B.2.2

voltage, and integrates battery charge state. The controller will control battery charge current by selectively and incrementally short circuiting series strings of solar cells in the array until the desired battery-charge-current level or voltage limit has been surpassed. Assuming that array orientation to the sun is maintained constant and that equilibrium conditions are achieved within the power system, the controller would "dither" about the limit by shorting and unshorting the array element which produces the desired effect.

2.4 Low Voltage Sensing System

A redundant Low Voltage Sensing System (LVSS) will be incorporated in the power system to protect the spacecraft batteries from excessive and potentially damaging discharge. In the event of a low voltage fault on the main power bus, the LVSS, acting as a circuit breaker, disconnects all non-critical spacecraft electrical loads. Recovery from an under-voltage fault will be performed manually by ground controllers so that failure, if it occurred, may be identified and isolated. Should the under-voltage circuit breaker itself prove defective, its control may be overridden by ground command.

3. Thermal Control Subsystem

The thermal control subsystem proposed for the spacecraft is semi-active through the use of louvers to control the heat loss to space. In addition, electrical heaters are used as necessary for heating the boom mechanisms before deployment and for more precise battery temperature control. All these heaters are commandable on or off. Active thermal control techniques are required. Louvers are operated by bimetallic elements, thus they require no power. The precise need will be established by detailed analysis during the design phase. Battery heaters are normally needed because of the close temperature control required.

Radiators located above the louvers will use surfaces with low solar absorptivity and high infrared emissivity. The remainder of the spacecraft will be covered with multilayer insulation blankets.

4. Command Subsystem

4.1 Subsystem Features

The fully redundant command subsystem proposed is shown in Figure VII.B.4. Two dipole antennas channel uplink command signals to respective receivers. Each receiver demodulates the VHF command signal and outputs the Fast Frequency Shift Keyed (FFSK) command baseband to respective FFSK bit detectors. Each bit detector demodulates the FFSK uplink message and outputs command data to its respective command processor which will be microprocessor based. Both command processors will act on the uplink message but only one processor, via an address select, will output the desired command signals.

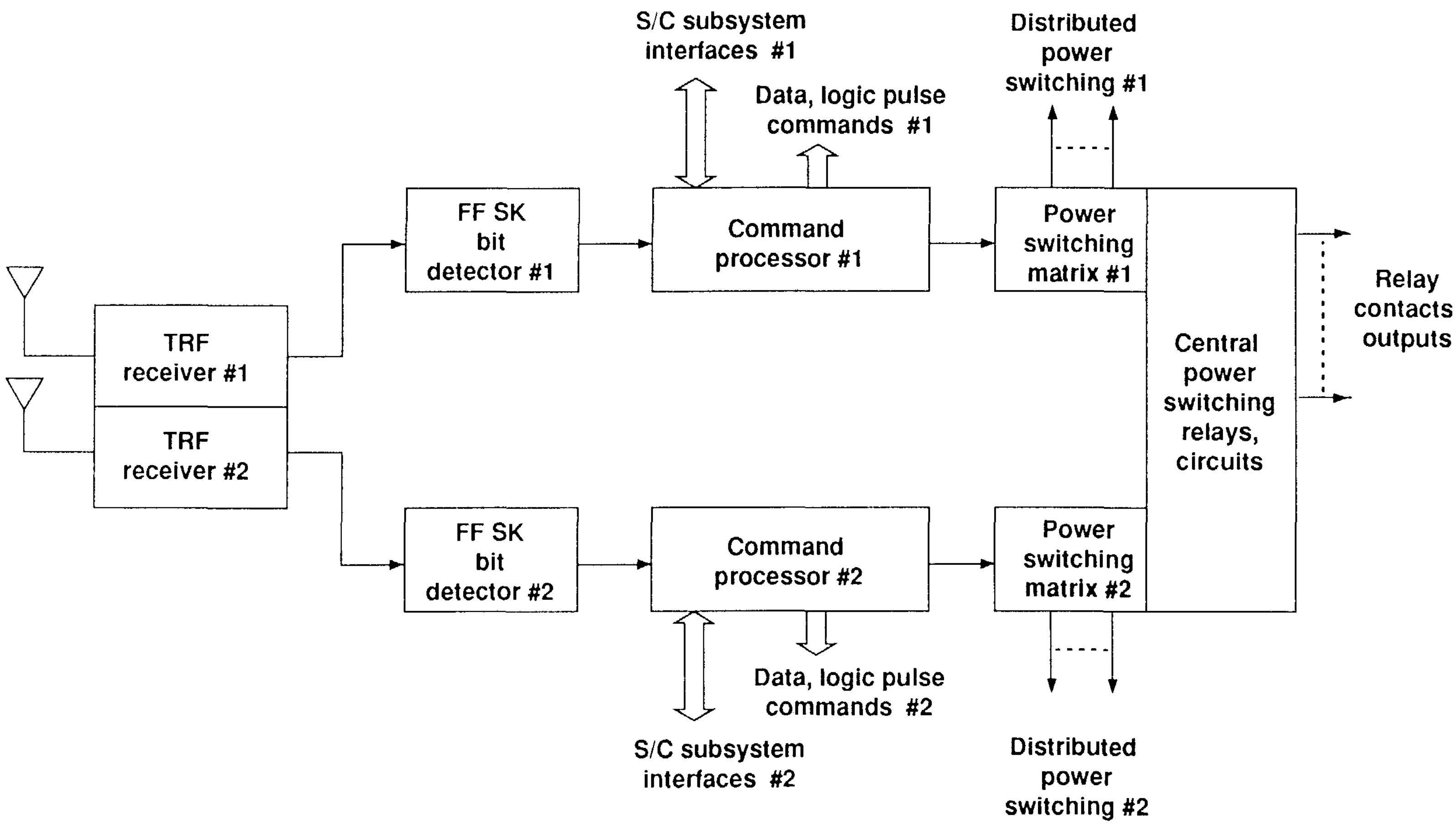


Figure VIII.B.4

The types of commands include the following: relay, pulse, data, memory loading, memory load verification, and logic level. A central core of power switching will be provided with other power switching functions being distributed as required. Commands can be executed on a real time or delayed basis. A bi-directional active interface with the telemetry system will provide for various semi-autonomous satellite operations.

4.2 Command Uplink

To capitalize on equipment developed for, and proven by, other space programs over the years, a VHF command uplink has been chosen. The characteristics of the command link (standard uplink channel) are shown in Table 4. The receiver antennas will be mounted on the ends of the solar panels.

Table 4

Command link characteristics

Center frequency	Approximately 148 MHz
Peak power	12 dBWatts
Carrier modulation	FFSK = 4.8 kpbs
Ground Antenna	8-turn Helix, gain = 16 dBi
Spacecraft antenna	Gain -10 dBi over 90% of sphere
Receiver type	Tuned RF
Receiver power required for $<<10^{-6}$ BER errors	> or = -95 dBm

The link is capable of providing > or = - 75 dBm to the command receiver for a STARNET altitude of 1300 km at ground station elevation angles at 5^{o} or above, thus providing a minimum command margin greater than 15 dB.

5. Telemetry Subsystem

5.1 Subsystem Features

The fully redundant telemetry subsystem proposed is shown in Figure VII.B.5.1. Each channel will be micro-processor based. A telemetry channel will be selected via the command system to process the downlink data. Each telemetry processor will control its respective multiplexers to gather analog and digital housekeeping information for subsequent formatting and transmission back to earth. Each telemetry processor will generate clock and timing signals as required by other on-board systems.

The telemetry subsystem will include programs for analysis of collected data. An interface with the command processors will allow semi-autonomous operations by requesting action resulting from analysis of designated telemetry data. This same interface will also function to perform command memory load verification.

5.2 Spacecraft telemetry link design

A standard downlink 137 MHz VHF channel is proposed. Baseline parameters for the spacecraft telemetry link are given in Table 5.

Table 5
Telemetry link characteristics

Center frequency	Approximately 137 MHz
Transmitter power	9 dBWatts
Data rate	9600 bps
Modulation	FFSK
Spacecraft Antenna	> or = -6 dBi over 80% of sphere
Ground antenna	Gain = 16 dBi

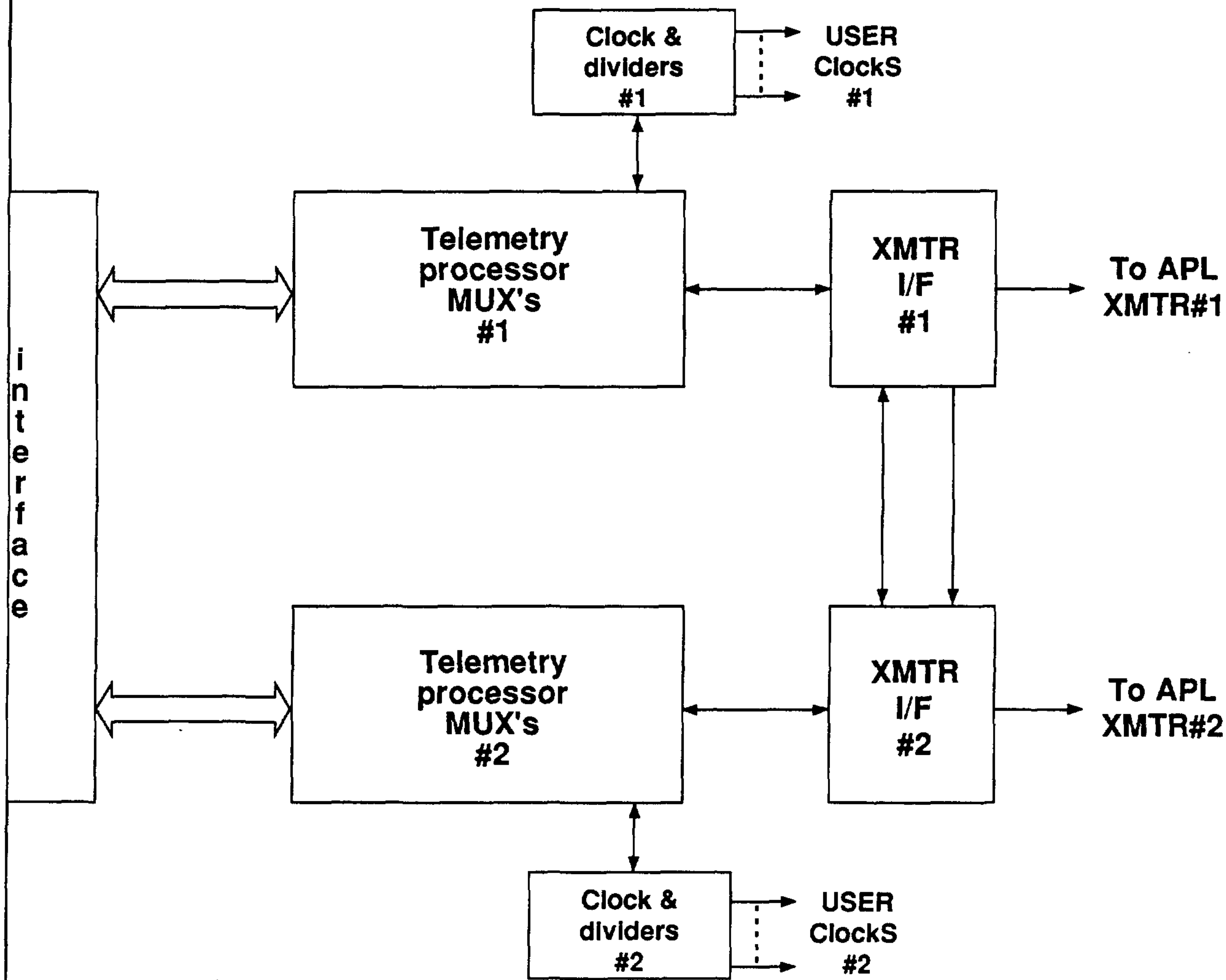


Figure VII.B.5.1

The STARNET spacecraft will contain redundant low-power telemetry transmitters connected to solar panel mounted antennas. Prior to gravity-gradient stabilization, the spacecraft may be in any attitude. As a consequence, an omni-directional antenna system is required. Coverage over a large percentage of the sphere about the satellite can be obtained by arraying the quadrifilar helix antennas and a dipole antenna which individually supply hemispherical coverage.

With the link parameters indicated in Table 5, recovery of spacecraft telemetry with a bit error rate less than 10^{-5} will be provided for an altitude of 1300 km at ground station elevation angles of 10° or above. An additional margin of approximately 6 dB could be obtained after gravity-gradient stabilization by switching to the earth-looking antenna only.

6. Attitude Subsystem

The mission requires orientation of the antennas to approximate local vertical, with no requirement for yaw stability. Pitch and roll will be held to less than + or - 5° by gravity-gradient stabilization. A motorized boom will provide the necessary inertia configuration for gravity-gradient orientation. Energy dissipation for stability is provided by four passive magnetic hysteresis rods, one in each solar panel spar. Passive gravity-gradient stabilization such as this has been demonstrated on numerous spacecraft.

Energy dissipation to assure stability will be provided by two passive ball-in-tube nutation dampers.

Attitude knowledge is required to perform the maneuvers necessary for the stabilization adjustment phase. This is provided by a three-axis vector magnetometer and digital sun sensors. Magnetometer and sun sensor data are telemetered and ground processing enables attitude determination.

7. Antenna Subsystem

The system will operate simultaneously in the VHF frequency bands between space and earth. A single antenna structure will be used for the downlink at 148 MHz and the uplink antenna at 137 MHz will use a separate antenna.

In all cases, the antennas are helixes designed for broad beamwidths (FOV = 70°) and circular polarization to support VHF earth terminals with 5° elevation angles.

C. GROUND SEGMENT

1. General

For the United States, the ground segment basically comprises two (2) Processing, Analysis and Control Center (PACCs), and four (4) Command and Data Acquisition (CDA) stations to communicate with the STARNET satellites and the user terminals (see Figure VII.C.1(1)).

The ground segment was designed to produce a high degree of reliability and redundancy. Each subsystem has a modular architecture to handle anticipated use of the system, (see Figure VII.C(2)).

The master PACC will be located at STARSYS, Inc. headquarters on the East Coast (PACC East) and the redundant PACC will be located on the West Coast (PACC West).

PACC required performance is dependent on the overall system use factor. Therefore modular architecture has been chosen which provides easy performance level upgrade without interruption of service. The processing systems are built around two (2) layers of duplicated LAN using standard mini-computers acquired from a major OEM (IBM, DEC, HP, etc.), (see Figure VII.C.1(2)).

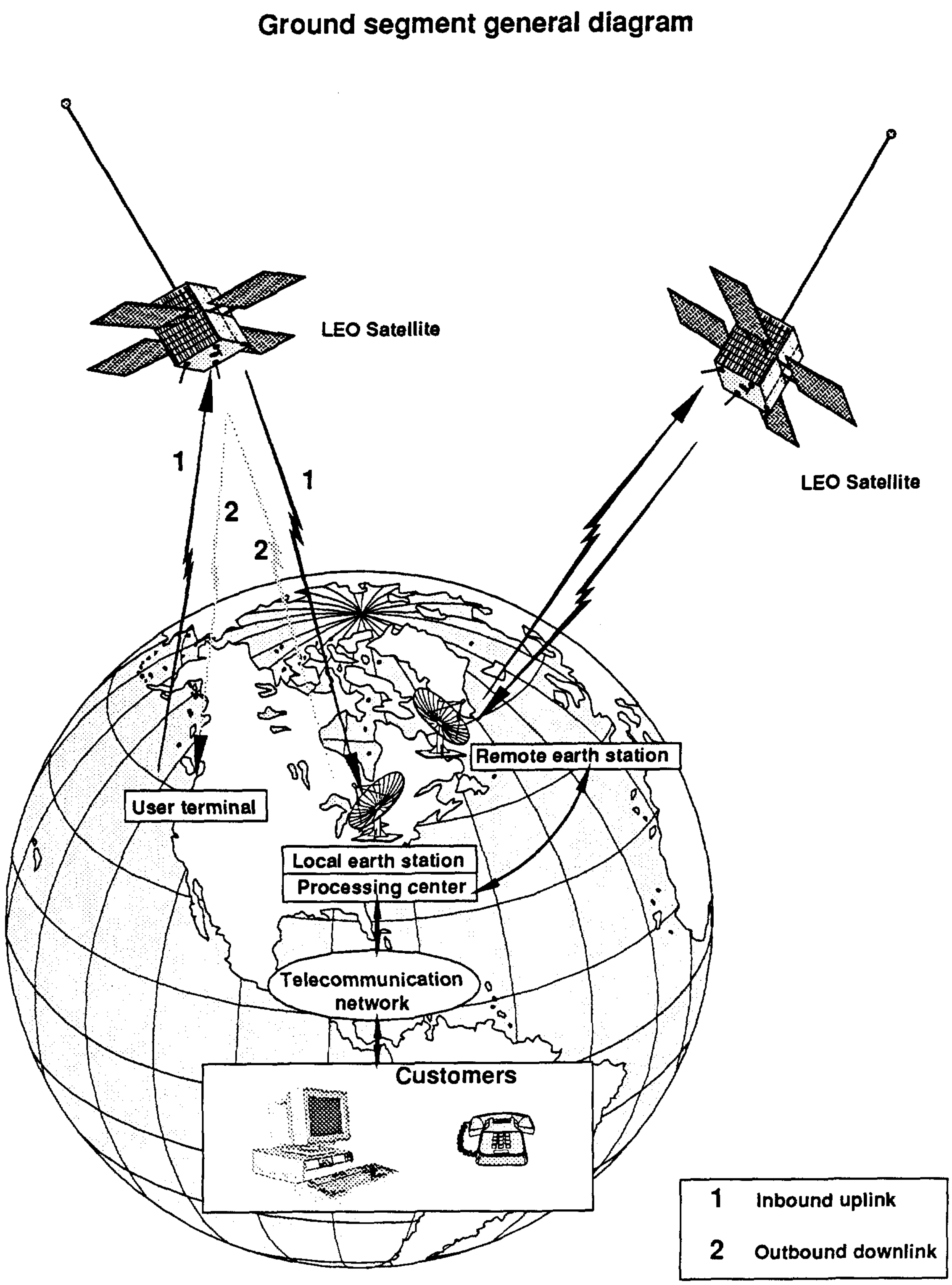
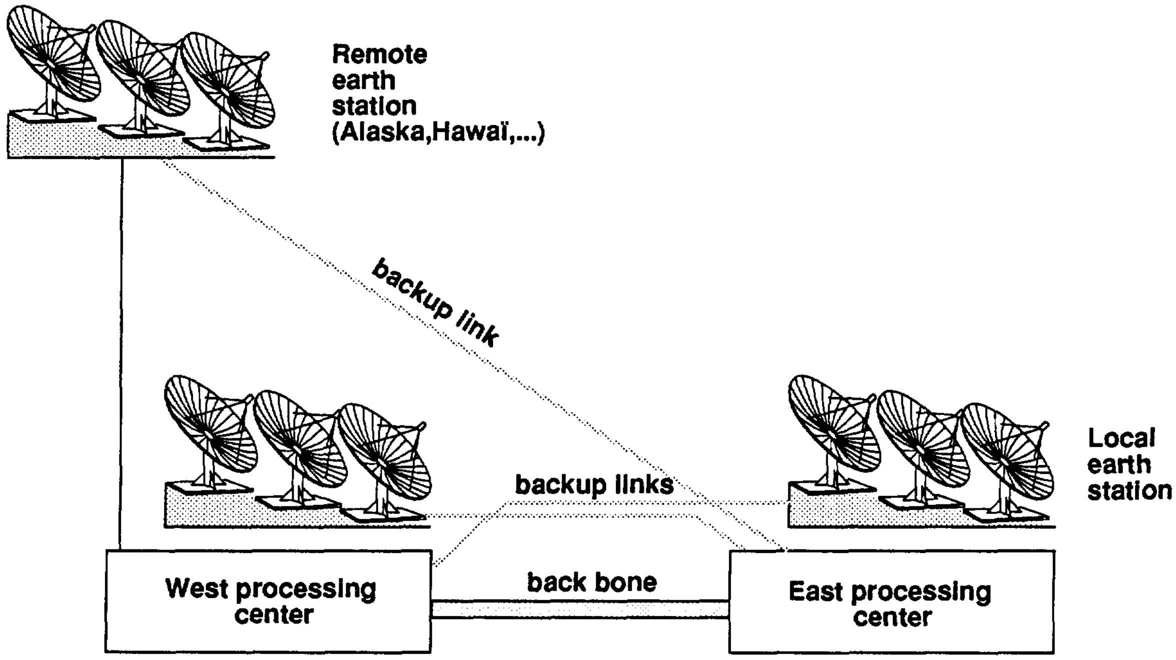


Figure VII.C.1(1)



Ground segment architecture

Figure VII.C.1(2)

The main functions of the PACCs, which include a CDA, are: communication, position processing, message handling, user interface, and system monitoring, and comprise the following subsystems:

1.1 PACC Subsystems

- **communication interface**: to communicate with the CDA stations to receive messages and raw data, and the ranging and Doppler measurements. This interface also manages the high capacity (n x 56 kbps) "back-bone" communications link between the two processing centers.

- **location subsystem**: to compute the user terminal location according to user terminal type and class of service. This subsystem comprises a satellite location determination module to process the messages from the Reference Calibration Platforms (RCPs - a group of precisely surveyed benchmark terminals arranged around the world), and a user terminal location module to process the user terminal messages.

- **message handling subsystem**: to route the messages through the system, to/from the CDAs, to/from the other PACC, to/from the telecommunication networks.

- **administrative subsystem**: to manage the administrative functions of the system:

  . terminal and user management,
  . user billing
  . user service.

- **user interface subsystem**: this subsystem starts as an interface with the telecommunication networks (X25, X400, ...) and houses value-added services such as:

  . 1-800 STARNET voice interface,
  . mail-box,
  . proximity service.

  The user interface shall extensively use the resources of modem telecommunication networks (ISDN, 800 numbers, etc.) to provide cost effective, reliable and user friendly operations. Service based interfaces (e.g., to emergency service) are also available as computer-to-computer connections.

- **monitoring subsystem**: comprising the following :

  . satellite control: satellite health monitoring,

  . CDA station control: station alarm monitoring and tracking strategy optimizations,

. system control: traffic and load observation,

. processing center control: center behavior control, automatic reconfiguration procedures.

2. Command and Data Acquisition Stations (CDAs)

The CDAs communicate with the STARNET satellites and provide:

- the OUTBOUND uplink to provide a timing synchronization for ranging, routing messages toward the user terminal, and for commanding the satellite subsystems for satellite health and safety purposes;

- the INBOUND downlink to receive messages and location information from the user terminals.

In addition, the CDAs will handle satellite housekeeping telemetry and telecommand.

Two (2) CDA stations will provide footprint coverage over the CONUS and will be co-located with PACC east and PACC west. See Figure VII.C.2-1. Two (2) additional CDA stations will be installed, one in Alaska, and another in Hawaii. These latter stations will provide coverage of North America (Canada and Alaska) and the Pacific Ocean, thus providing complete coverage of the U. S. See Figure VII.C.2-2.

These Figures, (with 5° template), depict the limits within which a satellite can be received. The actual system coverage is much greater because each satellite communicates with all user terminals within its own footprint.

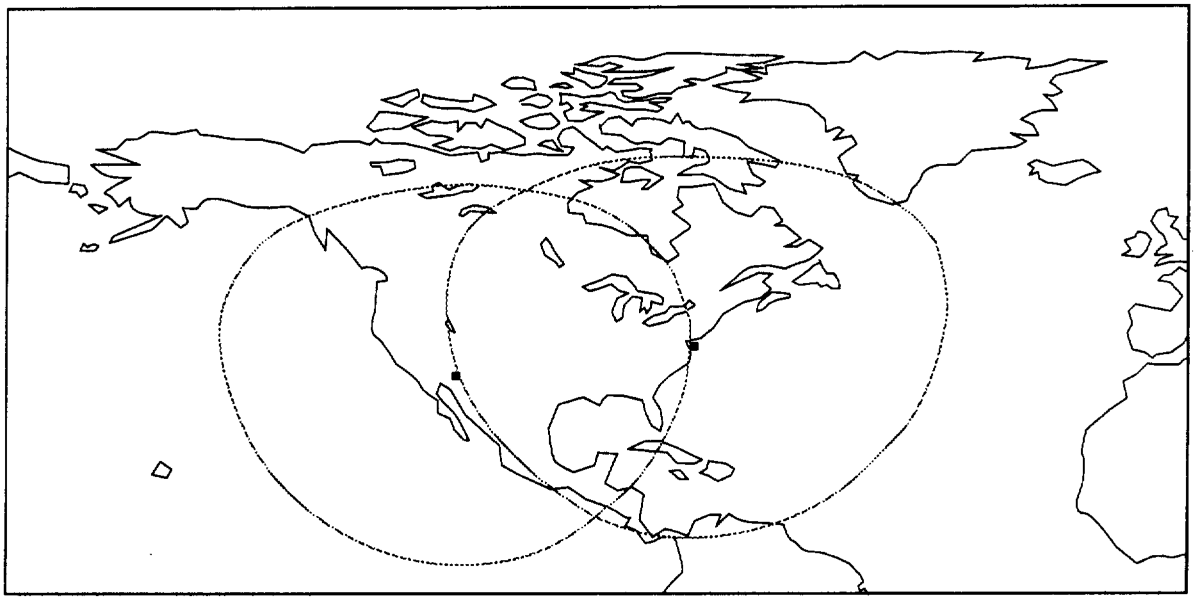


Figure VII.C.2-1

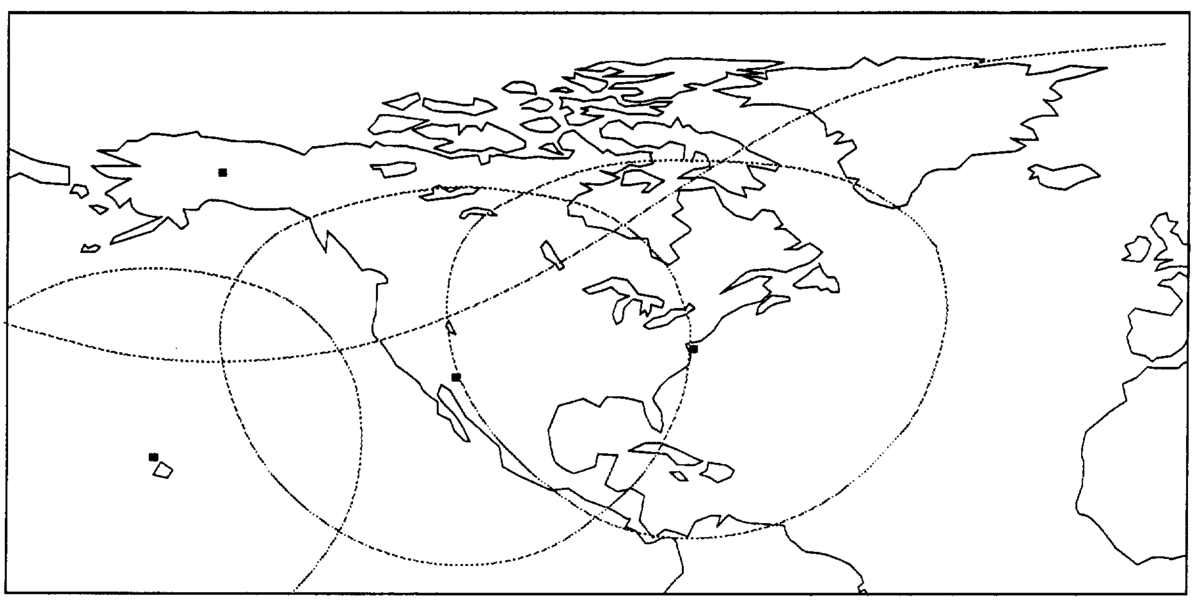


Figure VII.C.2-2

Though the STARNET constellation deployment plan provides for first coverage opportunities for the U. S., future plans include European and North Atlantic coverage from a CDA station in France. Figure VII.C.2-3 shows the coverage of the European system.

Each CDA will house a Reference and Calibration Platform (RCP) to be used for satellite location determination. Additional RCPs are located world-wide to increase the satellite position accuracy as well as the terminal position accuracy through differential positioning.

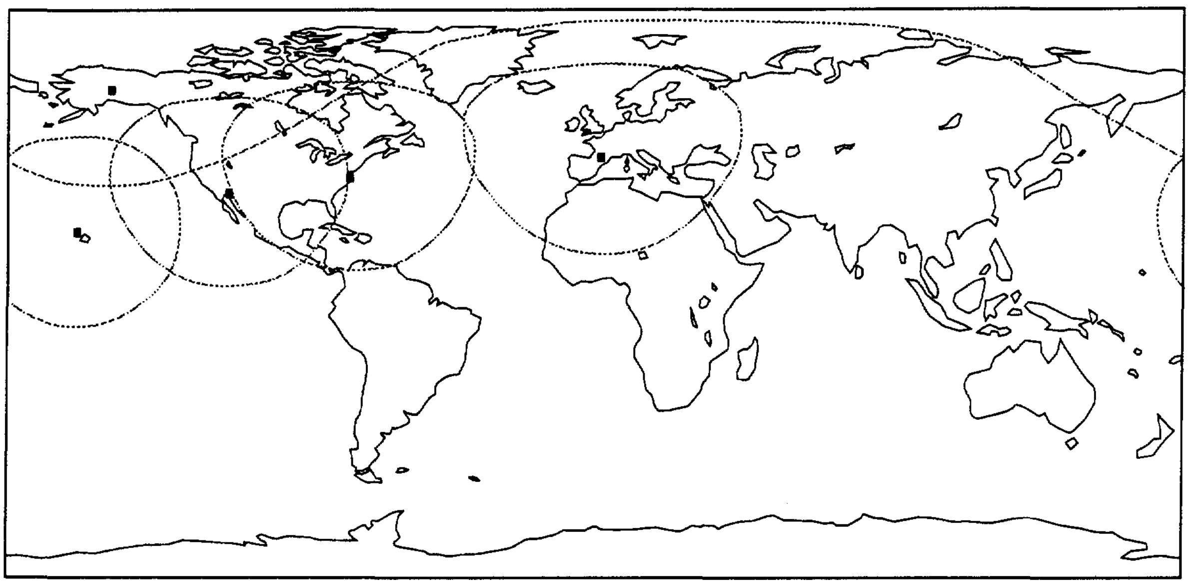


Figure VII.C.2-3

2.1 CDA Subsystems

2.1.1 Antenna

Each CDA will contain three (3) complete antenna systems. Each antenna will have a minimum of 16 dbi gain, and will have transmit and receive capability. Each antenna will be mounted on a two-axis positioner which will be pedestal mounted.

Two (2) antennas will be required to track two (2) different satellites when two (2) satellites are in view (the footprints overlapping). The third antenna system will be used as a spare, providing redundancy should one system fail.

The antenna system will be computer driven. Orbital elements will be routinely scheduled, computed, and sent to the CDA stations by the master PACC (PACC East).

2.1.2 Receiving

The receiving subsystem comprises low noise amplifiers, receivers and a number of demodulators and signal processing units to be dimensioned according to the number of channels and the effective system use.

This subsystem also performs accurate time stamping and frequency measurement on the INBOUND link messages; these measurements are then used in the processing center for positioning computation. This subsystem will contain low noise amplifiers, receivers, and demodulators. The signal processing units will be dimensioned according to the number of channels and the effective system usage.

2.1.3 Transmission

This subsystem comprises signal processors, modulators and output amplifiers. Transmissions are synchronized to the time reference subsystem.

2.1.4 Time Reference

Each CDA will contain a high accuracy timing source connected to a WWV receiver or similar timing standard. The timing source will provide the input for the ranging subsystem, message tagging subsystem, and the antenna positioning subsystem.

2.1.5 Reference and Calibration Platform

Each CDA station will house a precisely surveyed Reference and Calibration Platform (RCP) to be used for satellite position determination, as well as the user terminal location through differential Doppler. Another ten (10) RCP's will be spaced world-wide to further increase the satellite's position accuracy, and to serve this community as STARNET evolves.

2.1.6 Computer

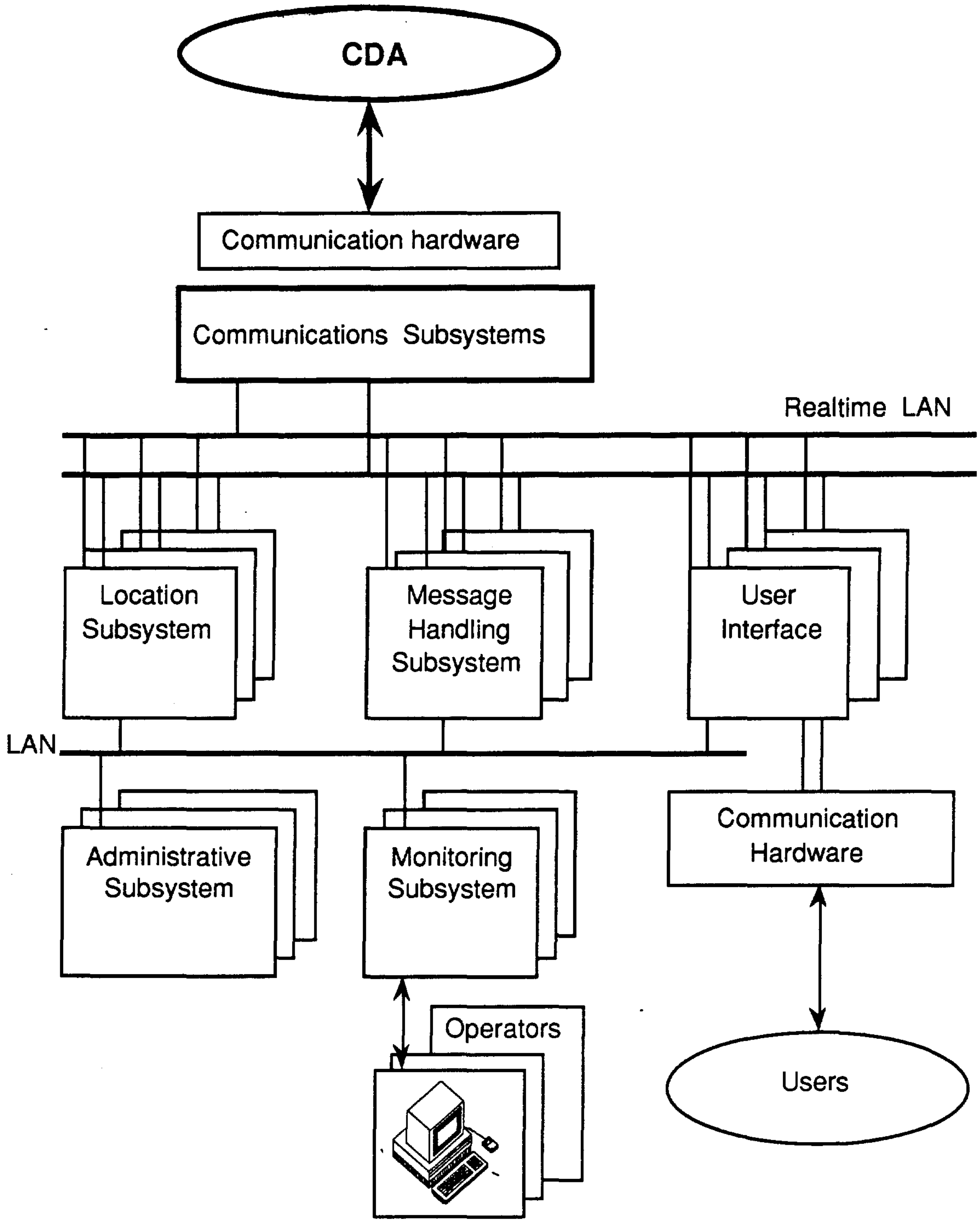
Each CDA will contain a number of micro- and mini-computers integrated through redundant LANs. Micro-computers will also be used for message routing and handling.

2.1.7 Communication

The CDAs will be interfaced to the Processing, Analysis and Control Centers (PACCs) with standard 56 kbps digital lines. This subsystem will have a buffering capability to avoid in-and-out message losses. This subsystem also handles alternative line routing in the event of primary line failure.

3. Processing, Analysis and Control Centers (PACCs)

Two (2) PACCs will be operated in the CONUS, one on the East Coast (PACC East), the other on the West Coast (PACC West). The two (2) centers are geographically located such as to best serve the needs of the regional users. Each center will primarily process the data for the users in their respective regions, but each will have the capacity to process all of the CONUS data (see Figure VII.C.3).



Processing and Analysis Control Center (PACC)

Figure VII.C.3

The main functions of the PACCs are:

- message handling
- location processing
- user interface
- system command and control.

3.1 PACC Subsystems

3.1.1 Communication

The PACC communications subsystems will communicate with the CDAs to receive user terminal messages, raw ranging data, and Doppler measurements. The subsystem will transmit user terminal messages, satellite commands and orbital information to the CDAs. This subsystem will also manage the high capacity interface between the two (2) PACCs.

The communications subsystem will interface the PACCs using standard 56 kbps digital links. This subsystem will have a buffering capability to avoid in-and-out message losses. This subsystem will also handle alternative routing in the event of failure of the link with the processing center.

3.1.2 Positioning

The positioning subsystem will compute the user terminal locations according to terminal type and class of service, as well as the satellite orbital data.

3.1.3 Message Handling

The message handling subsystem routes messages through the system, to and from the CDAs, to and from the other PACCs, and to and from the telecommunication network.

3.1.4 Administrative

The administrative subsystem manages the terminal and user informational data bases, user billing, and other interfaces dealing with user services.

3.1.5 User Interface

This subsystem starts as an interface with the telecommunication network and houses the following value-added services:

- 1-800 STARNET voice interface
- User mail box
- Proximity service (e.g., "10 miles NW Chicago")
- Service based Computer-to-Computer (CTC) interfaces.

3.1.6 Command and Control

STARSYS, Inc. will operate two (2) STARNET Operations Control Centers (SOCCs), one of which will be co-located with PACC East. A backup SOCC will be co-located at PACC West.

The SOCCs will be operated twenty-four (24) hours a day, seven (7) days a week, since there is always at least one satellite in the field of view. Outside critical phases (such as a launch), monitoring of each spacecraft will be done on a daily basis.

The SOCCs will also have the responsibility to compute the orbital elements for the twenty-four (24) satellites and to forward these elements to all the regional CDAs operating world-wide. These orbital elements are also forwarded to the CDAs for tracking purposes.

The SOCCs provides:

- satellite control for satellite telemetry health and safety monitoring